Development of Elliptic Orbit Rendezvous Analytical and Operational Techniques

Project Number: 96-16

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Purpose

The objective of this research is to develop the strategies and capabilities needed to accomplish highly elliptic orbit rendezvous in future mission design. This project is exploring the subject using both theoretical and numerical approaches, to categorize and evaluate various options for elliptic rendezvous, and to develop and recommend operationally efficient elliptic rendezvous procedures.

Background

Rendezvous of two spacecraft in orbit had its beginnings in the Gemini and Apollo programs and has become almost commonplace in the Shuttle era. Its continued importance to our space program is illustrated through the Shuttle-Mir missions as these flights continue to prepare us for the *International Space Station* era. Through these programs, rendezvous between two vehicles in nearly circular orbits has become a predictable, highly standardized procedure. However, not all spacecraft occupy nearly circular orbits and rendezvous in elliptic orbits, presenting a whole new set of problems. The two spacecraft's velocities vary with position in the orbit (true anomaly) and thus, the relative motion is more complex. While many works appear in the literature which address various aspects of the elliptic relative motion problem (mostly in a theoretical vein), there remains an immense gap in knowledge where practical targeting algorithms and operationally feasible rendezvous planning is concerned. This research seeks to narrow that gap.

Approach

The approach being used involves four interrelated tasks. The first is literature research. Through this research the principal investigator (PI) discovers what efforts have already been made in the field and which findings and methods lend themselves to modification and extension for this project. Literature research also provides results to which the PI may compare her ongoing investigations. The second, and perhaps the largest task, is the development of computer programs that facilitate the study of elliptic rendezvous. These include, but are not limited to, routines to propagate the motion of two vehicles in a suitable relative coordinate system, to calculate necessary changes in velocity (Delta-V's) to move the vehicles from one relative state to another, and methods to evaluate which rendezvous scenarios are "best." The third task is to use the software developed to study and evaluate options for accomplishing elliptic rendezvous. Then, in the fourth task, the results are analyzed, and strategies for efficient, operationally desirable rendezvous will be formulated.

Accomplishments

During the first year of the project in progress, three of the four outlined tasks were reported. The literature study task was mostly completed in that first year. In the second year, periodic checks for new papers on elliptic rendezvous have been made and a number of references dealing with genetic algorithms have been collected. A genetic algorithm is a type of optimization scheme that works in a way that is analogous to the natural processes of genetics and evolution. This type of scheme is being evaluated by the PI as a possible means for sorting through the overwhelming number of parameter combinations that could be used in elliptic rendezvous to identify "optimal" rendezvous scenarios.

In the area of computer code development, the significant progress that was made in the first year was built upon in the second. The relative motion targeting and propagation programs were improved to accept inputs and provide outputs in curvilinear and local vertical-local horizontal (LVLH) relative coordinates, as well as absolute Cartesian coordinates and orbital elements. In addition, the propagator was upgraded to handle nonspherical Earth gravity terms (J2–J4) and solar and lunar perturbations.

Work on the parametric studies task, which was only beginning at the end of the project's first year, has progressed nicely. Relative motion in coelliptic and scaled elliptic orbits for some candidate orbits has been studied and found to closely duplicate work done by Kachmar, Shepperd, and Chu. Also, a number of terminal rendezvous studies have been done, some with orbits similar to those AXAF will occupy over its 10-year lifetime, to characterize the effects of initial true anomaly and transfer time selections. Also, since the capability to model perturbations has been added to the relative motion propagator, some studies have been done to determine which perturbations can be neglected and in what cases. In addition, with the inclusion of perturbing forces, variations in the "out of plane" orbital elements (inclination, right ascension of the ascending node and argument of perigee) come into play, providing even more control parameters in this optimization problem. Some preliminary work in studying the effects of these elements has been done.

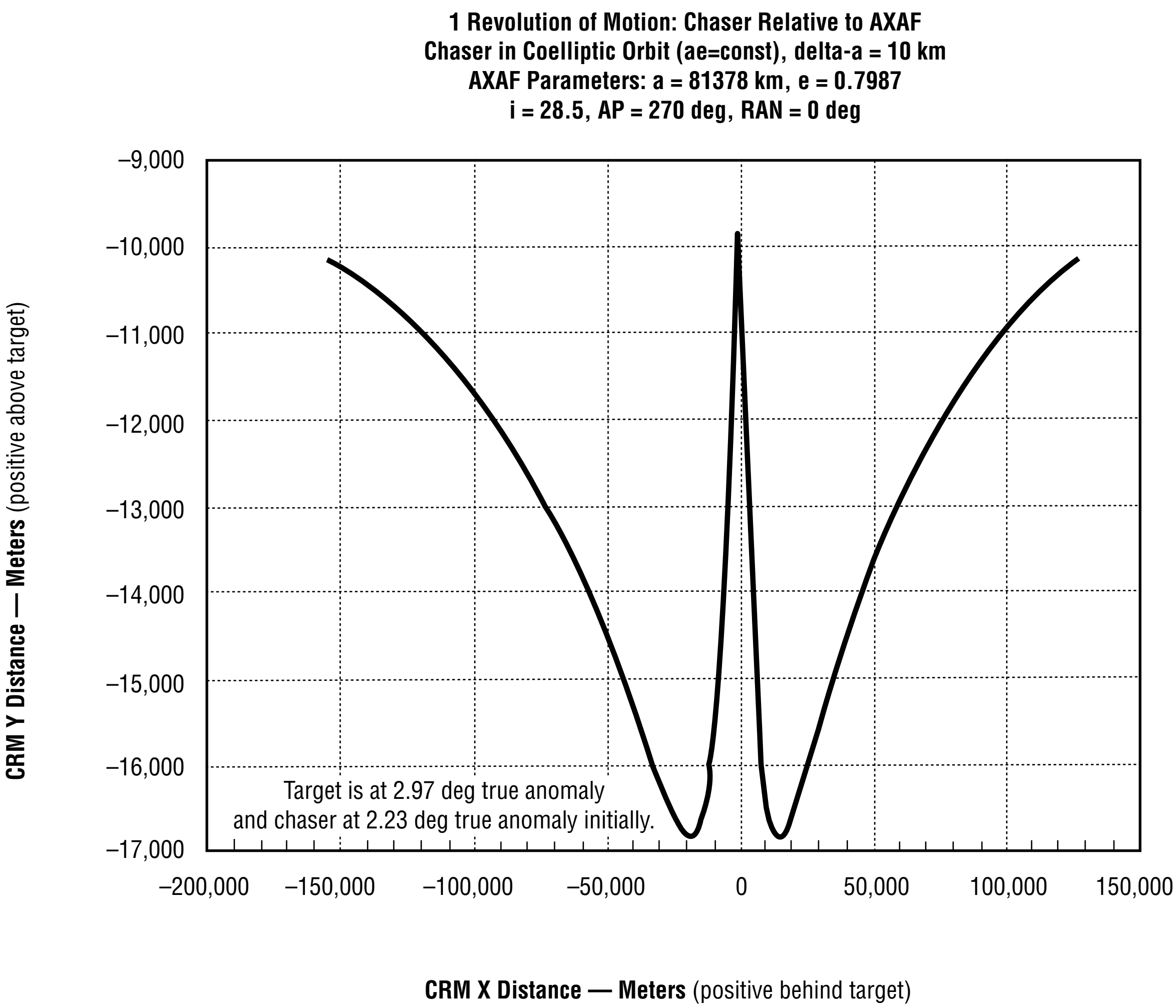

FIGURE 50.—Representative motion of chaser vehicle relative to target vehicle.

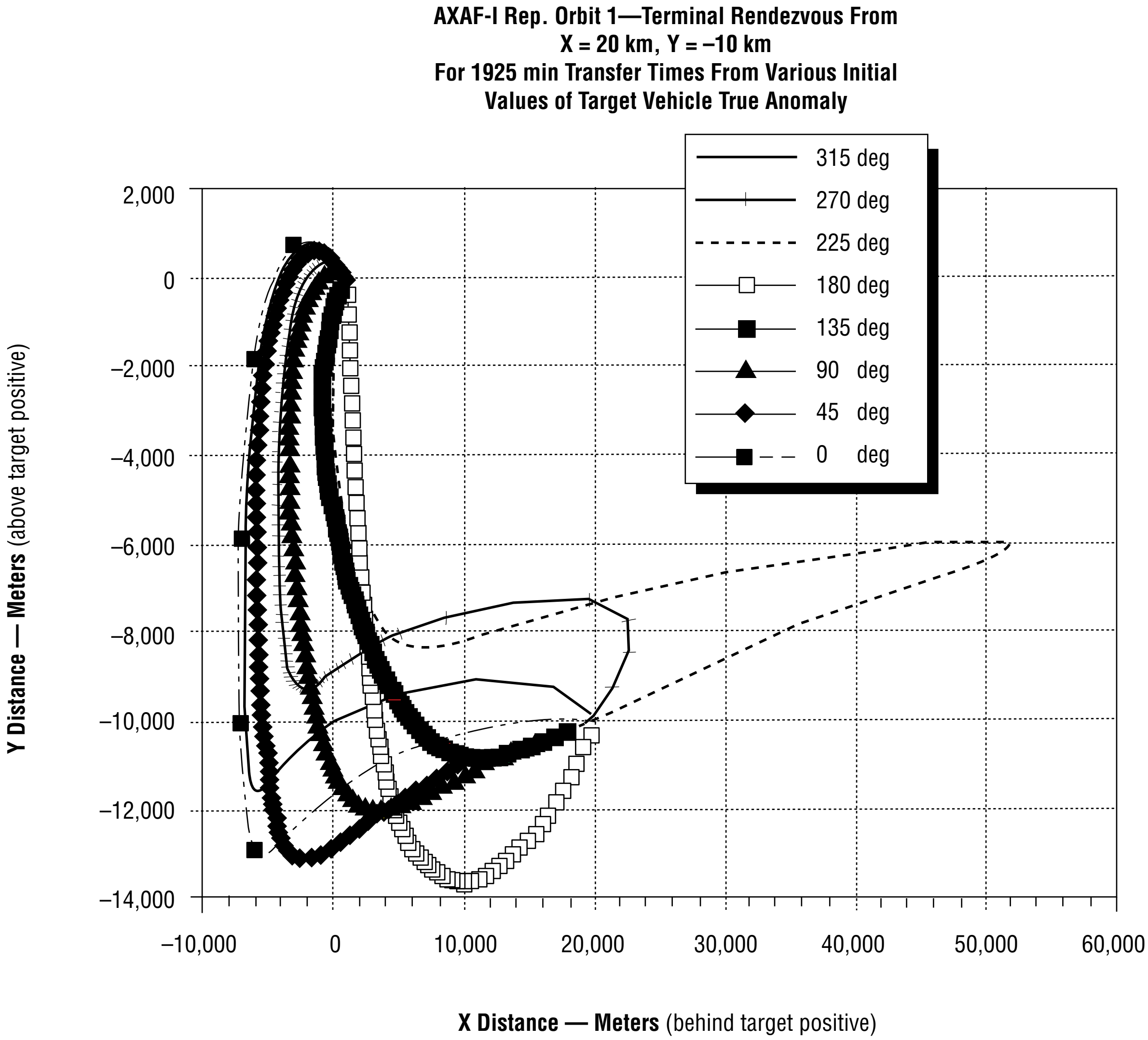

FIGURE 51.—Representative terminal rendezvous paths with various transfer times.

Task four is the final step of summing up results and recommending feasible scenarios for highly elliptic orbital rendezvous. As such, this task remains to be done. A few preliminary results that should be mentioned are as follows. Candidate final rendezvous maneuvers from 20 km behind and 10 km below a target vehicle to 1 km behind a vehicle in an AXAF-type orbit reveal favorable approach paths and velocities when initiated at apogee and completed over half a revolution of orbit travel. However, these transfers are very long (approximately 32 hours in an AXAF-type orbit). These extremely long terminal rendezvous maneuvers would represent a significant departure from circular orbit rendezvous procedures and could represent operational difficulties. Also, long transfers are subject to significant perturbation effects—especially if the orbits involved have a low perigee altitude.

Transfers with more typical transfer times (45–90 minutes) exhibit approach paths that seem operationally feasible yet constitute dramatic departures of the chaser vehicle from its natural relative motion in the phasing orbit, thus increasing the Delta-V of the maneuver. It is hoped that further parametric studies and optimization work will reveal combinations of orbital and rendezvous parameters that will produce terminal rendezvous maneuvers of reasonable duration, approach path and propellant usage.

Planned Future Work

In the year ahead the PI plans to continue the parametric studies with the software that has been developed to date and with genetic algorithm and calculus of variations-based optimization methods. These studies should lead to better understanding of the relative motion of elliptical orbit rendezvous and how it can best be undertaken operationally. The final product should be the identification and description of families of operationally optimal rendezvous scenarios as well as a battery of computer programs for their planning and evaluation. Some more development and evaluation of analytical targeting and propagation methods may be done although, at this time, this avenue does not appear promising.

Funding Summary ($k)

No funding was requested or has been received for this project.

Status of Investigation

This project was approved for 2 years with the PI charging half time to the effort. Due to other work demands, considerably less than half time has been worked, necessitating a request for a 1-year extension. This request has been approved and the PI anticipates that the project will be completed in FY98.